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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	421/31
First Inventor	Vicci et al.
Title	See 1 in Addendum
Express Mail Label No.	EK580750485US

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

1. [x] Fee Transmittal Form (e.g., PTO/SB/17) (Submit an original and a duplicate for fee processing)
2. [x] Applicant claims small entity status. See 37 CFR 1.27.
3. [x] Specification [Total Pages 30] (preferred arrangement set forth below)
   - Descriptive title of the invention
   - Cross Reference to Related Applications
   - Statement Regarding Fed sponsored R & D
   - Reference to sequence listing, a table, or a computer program listing appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings (if filed)
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
4. [x] Drawing(s) (35 U.S.C. 113) [Total Sheets 7]
5. Oath or Declaration [Total Pages 3]
   a. [x] unexecuted ~~Newly executed~~ (original or copy)
   b. [ ] Copy from a prior application (37 CFR 1.63 (d)) (for continuation/divisional with Box 17 completed)
      i. [ ] DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
6. [ ] Application Data Sheet. See 37 CFR 1.76
7. [ ] CD-ROM or CD-R in duplicate, large table or Computer Program (Appendix)
8. Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)
   a. [ ] Computer Readable Form (CRF)
   b. Specification Sequence Listing on:
      i. [ ] CD-ROM or CD-R (2 copies); or
      ii. [ ] paper
   c. [ ] Statements verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

9. [ ] Assignment Papers (cover sheet & document(s))
10. [ ] 37 CFR 3.73(b) Statement (when there is an assignee) [ ] Power of Attorney
11. [ ] English Translation Document (if applicable)
12. [x] Information Disclosure Statement (IDS)/PTO-1449 [x] Copies of IDS Citations
13. [ ] Preliminary Amendment
14. [x] Return Receipt Postcard (MPEP 503) (Should be specifically itemized)
15. [ ] Certified Copy of Priority Document(s) (if foreign priority is claimed)
16. [x] Other: Check for $637.00

17. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in a preliminary amendment, or in an Application Data Sheet under 37 CFR 1.76:

[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application No.: ______/______

Prior application information: Examiner ______ Group / Art Unit: ______

For CONTINUATION OR DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

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Signature	Gregory A. Hunt	Date	November 27, 2000

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FEE TRANSMITTAL for FY 2001

Patent fees are subject to annual revision.

TOTAL AMOUNT OF PAYMENT ($) 637.00

Complete if Known	
Application Number	
Filing Date	
First Named Inventor	Vicci et al.
Examiner Name	
Group Art Unit	
Attorney Docket No.	421/31

METHOD OF PAYMENT

1. ☐ The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

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☒ Applicant claims small entity status. See 37 CFR 1.27

2. ☒ **Payment Enclosed:**

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FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	710	201	355	Utility filing fee	355
106	320	206	160	Design filing fee	
107	490	207	245	Plant filing fee	
108	710	208	355	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($)355.00

2. EXTRA CLAIM FEES

			Extra Claims		Fee from below		Fee Paid
Total Claims	38	-20** =	18	X	9	=	162
Independent Claims	6	- 3** =	3	X	40	=	120
Multiple Dependent					0	=	0

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	80	202	40	Independent claims in excess of 3
104	270	204	135	Multiple dependent claim, if not paid
109	80	209	40	** Reissue independent claims over original patent
110	18	210	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 282.00

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FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for *ex parte* reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	390	216	195	Extension for reply within second month	
117	890	217	445	Extension for reply within third month	
118	1,390	218	695	Extension for reply within fourth month	
128	1,890	228	945	Extension for reply within fifth month	
119	310	219	155	Notice of Appeal	
120	310	220	155	Filing a brief in support of an appeal	
121	270	221	135	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,240	241	620	Petition to revive - unintentional	
142	1,240	242	620	Utility issue fee (or reissue)	
143	440	243	220	Design issue fee	
144	600	244	300	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	710	246	355	Filing a submission after final rejection (37 CFR § 1.129(a))	
149	710	249	355	For each additional invention to be examined (37 CFR § 1.129(b))	
179	710	279	355	Request for Continued Examination (RCE)	
169	900	169	900	Request for expedited examination of a design application	

Other fee (specify) ____

*Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($) 0.00

SUBMITTED BY

				Complete *(if applicable)*	
Name *(Print/Type)*	Gregory A. Hunt	Registration No. *(Attorney/Agent)*	41,085	Telephone	(919) 493-8000
Signature	Gregory A. Hunt			Date	Nov. 27, 2000

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November 27, 2000

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Date of Deposit November 27, 2000
I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail to Addressee" service under 37 C F R. 1 10 on the date indicated above and is addressed to the Commissioner for Patents, Washington, D C 20231
Karen S. Flynn
Karen Flynn

Commissioner for Patents
BOX PATENT APPLICATION
Washington, D.C. 20231

Re: U.S. Patent Application for METHODS AND SYSTEMS FOR REACTIVELY COMPENSATING MAGNETIC CURRENT LOOPS
Our File No. 421/31

Sir:

Please find enclosed the following:

1. A U.S. patent application for METHODS AND SYSTEMS FOR REACTIVELY COMPENSATING MAGNETIC CURRENT LOOPS (30 pages; 38 claims, 6 independent);

2. Seven (7) sheets of formal drawings (7 pages);

3. An unexecuted Declaration (3 pages);

4. Utility Patent Application Transmittal (Form PTO/SB/05; 2 pages);

5. Fee Transmittal (Form PTO/SB/17; 1 page) in duplicate;

6. Information Disclosure Statement (2 pages);

7. Form PTO/SB/08A (2 pages) in duplicate;

8. Copies of cited references (6 references);

9. A check in the amount of $637.00 to cover the small entity application filing fee and the extra claims fees;

10. A return-receipt postcard to be returned to our offices with the U.S. Patent and Trademark date stamp thereon; and

11. A Certificate of Express Mail No.: EK580750485US.

Please contact our offices if there are any questions with respect to this matter.

Respectfully submitted,

JENKINS & WILSON, P.A.

Gregory A. Hunt

Gregory A. Hunt
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GAH/ksf

Enclosures

METHODS AND SYSTEMS FOR REACTIVELY COMPENSATING MAGNETIC CURRENT LOOPS

AN APPLICATION FOR

UNITED STATES LETTERS PATENT

By

Leandra Vicci
Siler City, North Carolina

Wayne D. Dettloff
Cary, North Carolina

Description

METHODS AND SYSTEMS FOR REACTIVELY COMPENSATING MAGNETIC CURRENT LOOPS

Related Application Information

This application claims the benefit of United States Provisional Patent Application No. 60/169,726, filed December 8, 1999, the disclosure of which is incorporated herein by reference in its entirety.

Technical Field

The present invention relates to methods and systems for reactively compensating magnetic current loops. More particularly, the present invention relates to methods and systems for adding reactive compensation to magnetic current loops to provide magnitude and phase uniformity along the magnetic current loops.

Related Art

Magnetic current loops are commonly used to transfer power and information between microelectronic devices. For example, in one system, a card reader, which includes one or more magnetic current loops, generates a magnetic field by energizing the magnetic current loops. A card, which includes a printed circuit board and one or more magnetic current loops,

receives power from the card reader through its magnetic current loops when the card is brought into close proximity to the reader. The card may also receive an information signal from the reader that is modulated on the power signal. The information signal may be a query to which the card responds by transmitting its own information signal to the reader. The reader receives the response from the card and an action takes place, such as the opening of a gate, the storing of identification information, etc.

Systems in which a microelectronic circuit receives power from a magnetic field can be used in warehouses so that a pallet of goods having an inductively-powered identification circuit need only be brought within the communication range of a reader in order to track the location of the goods in the warehouse. Such magnetic-current-loop-based communication systems provide a distinct advantage over conventional systems in which bar codes and bar code readers are used to track goods. Using bar codes and bar code readers to track goods is difficult because a bar code must be brought into very close proximity, e.g., within a few inches, to a bar code reader in order for the information to be read. In addition, bar codes must be read in a specified order and orientation and carry only limited information. Thus, magnetic-current-loop based communication systems provide a significant advantage over conventional bar code systems.

One goal of magnetic-current-loop-based communication systems is to increase the distance at which an electronic circuit can be powered by and communicate with the reader. For instance, in the warehouse example discussed above, it may be desirable for an identification circuit associated with a pallet of goods to be powered by and communicate with a reader at a

distance of about 3 meters or more from the reader. One way to increase the communication and powering distance in such a system is to increase the power transmitted by the reader. However, one problem with increasing the power is that regulatory agencies, such as the Federal Communications Commission in the United States, place restrictions on radiated power at given frequencies. These restrictions have prevented conventional systems from achieving the desired communications and powering distance.

In the United States, some Federal Communications Commission limits are based on radiated power at a distance of 30 meters from the source. One frequency range in which the restrictions on radiated power are less stringent than restrictions for other frequency ranges is the range centered at 13.56 MHz. For example, the FCC allows 100 microvolts per meter in the range of 13.56 MHz ± 7 kHz and only 30 microvolts per meter for frequencies immediately outside of this range. Accordingly, 13.56 MHz is commonly used for magnetic-current-loop-based communication systems. However, even with these decreased restrictions, it has been difficult to design a system that extends the magnetic field to the desired distance without violating regulatory standards.

Exemplary systems capable of achieving the desired goals of increasing the communication and powering distance without violating regulatory standards are described in International Publication No. WO 99/60512, published November 25, 1999, and United States Provisional Patent Application No. 60/169,726, filed December 8, 1999, the disclosure of each of which is incorporated herein by reference in its entirety. The systems described in the above-referenced patent applications include multiple

magnetic current loops positioned adjacent to each other and separately driven by in-phase current sources. Driving adjacent current loops with in-phase current sources produces a strong near field and a weak far field. As used herein, a near field refers to an electromagnetic field that is located within about 1 wavelength of the source of the electromagnetic field and a far field refers to an electromagnetic field at a distance of more than about 1 wavelength from the source.

A single magnetic dipole produces undesirably high far field radiation. For example, at a distance far from a single magnetic dipole, the dipole appears as a point source. The electric field strength of the single magnetic dipole decreases proportionally to $1/R^2$, where R is the distance from the single magnetic dipole. Because the field strength only decreases at a rate proportional to $1/R^2$, single magnetic dipoles are limited in the amount of transmitter power that can be applied.

The system described in the above-referenced patent applications relies on cancellation of the dipole effects of individual magnetic current loops to produce only quadrupole and higher order fields at distances far from the source. For example, if two identical magnetic current loops are placed adjacent to each other and driven in opposite directions, the dipole fields cancel at a distance far from the source. The remaining far field is a quadrupole field that decreases in strength at a rate of $1/R^3$. Similarly, using four identical, adjacent magnetic current loops driven in the appropriate directions results in cancellation of the dipole and quadrupole fields to produce an octupole field that decreases at a rate of $1/R^4$ in strength as one moves away from the source. Thus, the goal of the system described in the

above-referenced patent applications is to produce only higher order fields at distances far from the current loop sources.

One way to achieve magnitude and phase uniformity in magnetic current loop arrays is to divide each magnetic current loop into *N* sections and to separately drive each of the *N* sections with its own current source. However, such a system is complex and difficult to implement because it requires synchronization and uniformity among current sources. Accordingly, there exists a long-felt need for methods and systems for providing magnitude and phase uniformity of currents flowing through current loops in a magnetic current loop system.

Disclosure of the Invention

According to one aspect, the present invention includes methods and systems for providing reactive compensation for magnetic current loops in a magnetic-current-loop-based communication system. For example, each current loop in a magnetic current loop system may be divided into a number of segments. A single current source may be used to drive all of the magnetic current loops in the system. Reactive compensation may be provided for each segment so that the reactive compensation cancels the series reactance of each segment. Because the reactive compensation effectively cancels the reactance of each segment of the current loop, the phase delay along each current loop is nearly zero. As a result, the magnitude and phase of the current along each current loop will be nearly uniform at any given time. In addition, since adjacent loops are preferably divided and reactively compensated in a similar manner, lower-order fields resulting from inexact

compensation cancel. Since the dipole fields of such current loops cancel at distances far from the current loops, only quadrupole and higher order fields remain, which decrease rapidly as the distance from the source increases. As a result, near fields can be extended by increasing power without violating regulatory standards and without requiring unnecessarily complex drive electronics. The increased near fields result in a greater communication distance between readers and identification devices.

Accordingly, it is an object of the present invention to provide methods and systems for reactively compensating magnetic current loops in a manner that allows generation of strong near fields and weak far fields.

It is yet another object of the invention to provide a reader for a magnetic-current-loop-based communication system that includes reactively compensated current loops according to an embodiment of the invention.

Some of the objects of the invention having been stated hereinabove, other objects will be evident as the description proceeds, when taken in connection with the accompanying drawings as best described hereinbelow.

Brief Description of the Drawings

Preferred embodiments of the present invention will now be explained with reference to the accompanying drawings of which:

Figure 1 is a schematic diagram of a magnetic current loop driven by a current source;

Figure 2 is a schematic diagram of a transmission line model of the magnetic current loop illustrated in Figure 1;

Figure 3 is a schematic diagram illustrating a ladder network used to model the magnetic current loop of Figure 1;

Figure 4 is a schematic diagram of the ladder network in Figure 3 in which shunt loss is ignored;

Figure 5 is a schematic diagram of a magnetic current loop divided into a plurality of sections including reactive compensation for each section according to an embodiment of the present invention;

Figure 6 is a schematic diagram of a ladder network used to model the magnetic current loop of Figure 5, in which the series reactance is cancelled by the reactive compensation according to an embodiment of the present invention;

Figure 7(a) is a perspective view of first and second magnetic current loops including reactive compensation according to an embodiment of the present invention;

Figure 7(b) is a perspective view of first, second, and third magnetic current loops having reactive compensation according to an embodiment of the present invention;

Figure 8 is a schematic diagram illustrating a circuit model of a magnetic current loop in which capacitive reactance is chosen slightly off resonance according to an alternative embodiment of the present invention; and

Figure 9 is a schematic diagram of a reader including reactively compensated magnetic current loops according to an embodiment of the present invention.

Disclosure of the Invention

Figure 1 illustrates a magnetic current loop to which reactive compensation according to embodiments of the present invention may be applied. In Figure 1, magnetic current loop **100** comprises a conductor having a ring or loop configuration. Magnetic current loop **100** is driven by a current source **102**. Current source **102**, for purposes of the present invention, is a sinusoidal current source. Figure 2 is a transmission line model illustrating propagation of current around magnetic current loop **100**. Propagation of current around a loop conductor driven by a current source can be modeled to a good approximation as a linear transmission line driven at both ends by complementary current sources. In Figure 2, the complementary current sources are generally indicated by reference numerals **102a** and **102b**. Magnetic current loop **100** can also be divided into sections $\mathbf{104_1}$ through $\mathbf{104_n}$ for lumped constant modeling purposes, as will be described in more detail below.

Figure 3 is a ladder network illustrating lumped constant modeling of magnetic current loop **100** illustrated in Figure 2. For example, a transmission line can be modeled to arbitrary precision by a lumped constant ladder network representing the series connection of arbitrarily short sections of the transmission line. The shorter the sections, the better the approximation. In Figure 3, each of the sections $\mathbf{104_1}$ through $\mathbf{104_n}$ includes a series inductance L_s, a series resistance R_s, a parallel capacitance C_p, and a parallel resistance R_p. The series inductance L_s represents the series inductance of each section of the conductor. The series resistance R_s represents the resistance of each section. The parallel capacitance C_p represents the shunt

capacitance of each section, and the parallel resistance R_p represents the dielectric loss associated with the C_p of each section.

Figure 4 illustrates a simplified model of magnetic current loop **100** illustrated in Figure 3. In Figure 4, the dielectric loss represented by R_p is not included because the dielectric loss of a conductor in air is negligibly small. In embodiments of the invention in which current loop **100** is surrounded by a dielectric other than air, the dielectric loss may require consideration. However, for purposes of explanation, the dielectric loss is omitted. Thus, as illustrated in Figure 4, each section **104_1** through **104_n** includes series inductance and resistance L_s and R_s, respectively, and parallel capacitance C_p.

Figure 5 illustrates a current loop **100** in which each section **104_1** through **104_n** includes reactive compensation according to an embodiment of the present invention. In the illustrated embodiment, the reactive compensation includes *n* capacitors C_{s1}-C_{sn}. The capacitance value of each of the capacitors is preferably chosen such that the capacitive reactance of each section cancels the series inductance of each section. For example, the capacitive reactance of C_{s1} of section **104_1** preferably cancels the inductive reactance caused by the series inductance L_s of section **104_1**. The same is preferably true for the remaining sections of magnetic current loop **100**. That is, for each section of magnetic current loop **100**, the following expression is preferably true: $\omega L_{sn} = \frac{1}{\omega C_{sn}}$, where ω is the angular frequency of the current source, L_{sn} is the series inductance of the n^{th} section of magnetic

current loop **100**, and C_{sn} is the reactive compensation applied according to an embodiment of the present invention.

Once the series inductance is cancelled, only the series resistance and parallel capacitance of each section remains. Figure 6 illustrates an example of a circuit model of current loop **100** after application of reactive compensation according to an embodiment of the present invention.

In Figure 6, each section **104_1-104_n** of magnetic current loop **100** respectively includes series resistance R_{s1}-R_{sn} and parallel capacitance C_{p1}-C_{pn}. The parallel capacitance C_p of each section is sufficiently small that the RC phase delay formed with the parallel capacitance C_p and the series resistance R_s is negligible in all but the most extreme cases. The current drive symmetry of current sources **102a** and **102b** forms two counter-traveling waves of nearly constant magnitudes. The sum of the counter-traveling waves exhibits nearly perfect phase and magnitude uniformity throughout magnetic current loop **100**.

Figure 7(a) is perspective view of two magnetic current loops, each divided into a plurality of sections, wherein each section includes reactive compensation according to an embodiment of the present invention. Referring to Figure 7(a), magnetic current loops **100a** and **100b** are driven by sinusoidal current source **700**. Current loop **100a** is divided into four sections **701-704**. Similarly, current loop **100b** is divided into four sections **705-708**. Each of the current loops **100a** and **100b** includes reactive compensation to cancel the series reactance of each section. As discussed above, since inductive reactance may be the dominant component of the series reactance of each section, the reactance added to compensate each section may be

capacitive in nature. More particularly, in current loop **100a**, capacitor C_1 is added to cancel the inductive reactance of section **703**, capacitor C_2 is added to cancel the inductive reactance of section **702**, capacitor C_3 is added to cancel the inductive reactance of section **701**, and capacitor C_4 is added to cancel the inductive reactance of section **704**. Similarly, in current loop **100b**, capacitor C_5 is added to cancel the inductive reactance of section **708**, capacitor C_6 is added to cancel the inductive reactance of section **705**, capacitor C_7 is added to cancel the inductive reactance of section **706**, and capacitor C_8 is added to cancel the inductive reactance of section **707**.

When a current loop is divided into sections and reactively compensated such that the series reactance of each section is effectively cancelled, magnitude and phase of the current at any point on the current loop is nearly equal at any given instant and time. As a result, the magnitude and phase on adjacent current loops that are properly reactively compensated is also nearly equal. Moreover, since the current flows in one direction in one magnetic current loop and in the opposite direction in the other magnetic current loop, the dipole magnetic fields of the two current loops cancel. As a result, the only far field that remains is the quadrupole field. Since the quadrupole field decreases proportionally to $\frac{1}{R^3}$, where R is the distance from the source, it is possible to increase the power, thereby increasing the near fields without producing a corresponding strong far field that exceeds the appropriate regulatory agencies limit for electromagnetic radiation. Such a configuration is especially well adapted for radio frequency identification devices, as will be discussed in more detail below.

Although the embodiment illustrated in Figure 7(a) includes only two magnetic current loops, the present invention is not limited to such an embodiment. A magnetic current loop system may include any number of magnetic current loops. Suitable magnetic current loop systems to which reactive compensation according to the present invention may be added are described in detail in the above-referenced copending patent applications. Hence, a description thereof will not be repeated herein.

Figure 7(b) is a perspective view of a magnetic current loop system according to an alternative embodiment of the present invention. In Figure 7(b) a magnetic current loop system includes first and second magnetic loops **750** and **752** and a third magnetic current loop **754**. Each of the magnetic current loops **750**, **752**, and **754** includes reactive compensation on a per section basis as previously described. In addition, the outer magnetic current loops **750** and **752** are driven by a current source such that current flows in a first direction **756**. The inner magnetic current loop **754** is driven by a current source such that current flows in a second direction **758** that is opposite the first direction **756**. In addition, the current flowing through inner magnetic current loop **754** is preferably twice that of the identical currents flowing through outer magnetic current loops **750** and **752**. In addition, inner magnetic current loop **754** is preferably equally spaced from outer magnetic current loops **750** and **752**. In other words, the distances d_1 and d_2 in Figure 7(b) are preferably equal.

Given the configuration illustrated in Figure 7(b), the dipole and quadrupole fields produced by the magnetic current loops cancel at distances far from the magnetic current loops, i.e., more than 1 wavelength from the

magnetic current loop. As a result, only the octupole field remains, which decreases at a rate proportional to $1/R^4$. The system illustrated in Figure 7(b) is not limited to three magnetic current loops. For example, in an alternative embodiment, inner magnetic current loop **754** can be replaced by two magnetic current loops spaced closely to each other. In such an embodiment, the current flowing through each of the two magnetic current loops would flow in the direction **758** illustrated in Figure 7(b) and the current through each of the magnetic current loops would be i, rather than 2i. In this alternative embodiment, dipole and quadrupole cancellation would still be achieved.

Figure 8 is a schematic diagram of a magnetic current loop including reactive compensation according to an embodiment of the present invention in which the compensating reactance is chosen to be slightly off resonance for each section. series reactance series reactance. More particularly, each capacitor $C_{s(k)}$ where $1 \leq k \leq n$ is chosen to be slightly off resonance for its respective section ***(k)***, such that the series impedance of the compensated section is $Z_{s(k)} = R_{s(k)} - \frac{j}{\omega C_{e(k)}}$, where $C_{e(k)} = \frac{C_{s(k)}}{1-\omega^2 L_{s(k)} C_{s(k)}}$ is the effective series capacitance of section *(k)*. The value of $C_{e(k)}$ must be chosen such that $Z_{s(k)}$ of section *(k)* is a positive real constant $A_{(k)}$ times the parallel impedance $Z_{p(k)} = X_{(k)} Z_p$, where real number $X_{(k)}$ is the effective length of section *(k)*, $Z_p = \frac{R_p}{1 + j\omega R_p C_p}$ is the shunt impedance of a unit length section, and R_p and C_p are parallel resistance and capacitance respectively per unit length of section. Notice that except for $X_{(k)}$, $Z_{p(k)}$ depends only on the dielectric environment of the section. Therefore, the $Z_{p(k)}$ of all sections of a

loop are real valued multiples $X_{(k)}$ of the same complex constant if the loop is in a uniform dielectric environment, such as identical width runs on a printed circuit board. If input impedance $Z_{in(k+1)}$ of section $(k+1)$ is $D_{(k+1)}$ Z_p, then input impedance $Z_{in(k)}$ of section (k) is

$$Z_{in(k)} = Z_{s(k)} + \frac{Z_{p(k)} Z_{in(k+1)}}{Z_{p(k)} + Z_{in(k+1)}} = \left(X_{(k)} A_{(k)} + \frac{X_{(k)} D_{(k+1)}}{X_{(k)} + D_{(k+1)}} \right) Z_p = D_{(k)} Z_p ,$$

where $D_{(k)}$ is a real number. By recursion then, $Z_{in(k)} = D_{(k)} Z_p$ where $D_{(k)}$ is real for all (k). The current transfer function for section (k) is:

$$F(k) = \frac{Z_p(k)}{Z_{in}(k+1) + Z_p(k)} = \frac{X(k)}{D(k+1) + X(k)}$$

which is real, and which means theoretically that the input and output currents are exactly in phase. Consequently, the phase uniformity of the entire loop may be made arbitrarily good with suitably large choice of ***n***.

<u>Magnetic-Current-Loop-Based Communication Systems</u>

Figure 9 is a block diagram of a radio frequency identification tag reader **900** and a radio frequency identification tag **902** wherein the reader includes magnetic current loops having reactive compensation according to an embodiment of the present invention. In the illustrated embodiment, reader **900** includes driven magnetic current loops **904** and **906**. Magnetic current loops **904** and **906** are adapted to couple a radio frequency magnetic field to identification tag **902**. Magnetic current loop **908** is adapted to detect a radio frequency magnetic field produced by identification tag **902**. Detecting magnetic current loop **908** is preferably located between driven magnetic current loops **904** and **906** and spaced equidistantly from magnetic current loops **904** and **906**. Magnetic current loops **904** and **906** produce opposing

magnetic fields such that the dipole fields cancel. Because magnetic current loops **904** and **906** produce opposing magnetic fields, the magnetic field between magnetic current loops **904** and **906** cancels at a distance that is equidistant from magnetic current loops **904** and **906**. Accordingly, locating detecting magnetic current loop **908** equidistant between driven magnetic current loops **904** and **906** minimizes the detection of the signal produced by magnetic current loops **904** and **906** by magnetic current loop **908**.

Reader **900** includes circuitry for processing the field detected from identification tag **902** into usable format. In the illustrated embodiment, the circuitry includes a radio frequency preamplifier **910** for preamplifying the detected field, a down converter **912** for converting the detected field to a signal at a convenient frequency, bandpass filters and amplifier **914** for amplifying and filtering the signal in a band centered at the frequency of the output from down converter **912**, amplitude modulation detector **916** for detecting the amplitude of the signal, and comparator **918** for converting the signal into digital format. RF preamp **910** may be any conventional amplifier circuit that amplifies signals at the frequencies of interest. Down converter **912** may be a conventional mixer that subtracts the frequency of a reference signal produced by an oscillator **920** from the frequency of the detected field. Oscillator **920** may be any type of conventional resonator adapted to produce a signal at a frequency corresponding to the card communication frequency, which may be 13.56 MHz. Bandpass filters and amplifier **914** may include a conventional bandpass filter and an amplifier adapted to amplify the signal about the frequency produced by down converter **912**. Amplitude modulation detector **916** may be a conventional rectifier circuit that detects the amplitude

of a signal. Finally, comparator **918** may be a conventional comparator integrated circuit that produces a digital output based on the relationship between an analog input and a reference value.

On the driving side, reader **900** includes an amplitude modulator **922** and a linear power amplifier **924**. Amplitude modulator **922** may be any type of conventional amplitude modulator. Power amplifier **924** may be any conventional amplifier with a gain that is adjusted to produce a magnetic field in a range sufficient to communicate with tag **902** at a distance of at least about 3 meters from current loops **904**, **906**, and **908.**

In operation, reader **900** preferably continuously produces a magnetic field that will power a tag when the tag is brought within a predetermined distance of transmitting current loops **904** and **906**. When a tag, such as tag **902**, is brought into the range of magnetic current loops **904** and **906**, tag **902** rectifies the signal and utilizes the rectified signal to power a microprocessor resident on tag **902**. The microprocessor resident on tag **902** amplitude modulates a digital signal on a subcarrier which in turn varies the resonant frequency of its current loop to produce an amplitude modulation of the circulating current. Detecting loop **908** of reader **900** detects the amplitude modulated field from tag **902**. RF preamp **910** amplifies the detected field from tag **902**. Down converter **912** converts the amplified signal to the subcarrier frequency. Bandpass filters and amplifier **914** filter unwanted components from the signal and amplify the components of interest. AM detector **916** detects the amplitude of the received signal. Finally, comparator **918** converts the signal from the tag into digital format. The digital output from comparator **918** may be processed by a microprocessor resident in reader

900 to perform some useful functions. For example, if tag **902** is located on a product in a manufacturing facility, the information received from the tag may be an identification code or serial number for the product and the microprocessor of reader **900** may store the serial number in memory. Another example of information that may be produced by tag **902** is an access code to access a secure facility. In this instance, the microprocessor of reader **900** may grant or deny access.

Because magnetic current loops **904** and **906** include reactive compensation according to embodiments of the present invention, tag **902** can be read at a distance that is spaced from magnetic loops **904** and **906** without requiring a power increase at reader **900** that violates regulatory limits. In addition, because the individual sections of magnetic current loops **904** and **906** do not require separate power sources, the circuitry used to drive magnetic current loops **904** and **906** is simplified.

Although the multi-loop systems described above focus primarily on flowing currents in opposite directions in adjacent magnetic current loops, the present invention is not limited to such an embodiment. For example, in metrology, it may be desirable to drive Helmholtz coils at a high frequency. Helmholtz coils are of a particular geometry of two circular loops which at DC produce a region about their center where the field and its first spatial derivative are constant which may also be useful to accomplish in the RF band. The currents in the loops preferably flow in the same direction. Helmholtz coils are often used to cancel the DC magnetic field produced by the earth or other source within some defined volume. High frequency Helmholtz coils may be similarly used to cancel out interfering magnetic fields

at a high frequency. Alternatively, it may be desirable to create a high frequency magnetic field having a uniform magnitude within a defined volume.

Accordingly, reactive compensation may be added to current loop(s) and the current loops may be driven by currents flowing in the same direction to achieve magnetic field cancellation of an externally generated high frequency field, or production of a uniform high frequency magnetic field within a defined volume. Externally generated high frequency magnetic field cancellation may be useful in a laboratory in which it is desirable to have a zero-magnetic field. In this situation, the axes of the Helmholtz coils would be oriented parallel to the magnetic field to be cancelled, and driven by currents flowing in the same direction in order to achieve the cancellation.

It will be understood that various details of the invention may be changed without departing from the scope of the invention. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation—the invention being defined by the claims.

CLAIMS

What is claimed is:

1. A magnetic current loop system adapted to produce strong near fields and weak far fields, the magnetic current loop system comprising:

   (a) first and second magnetic current loops being divided into *k* sections, *k* being an integer, each of the *k* sections having a series reactance at a frequency;

   (b) k reactive compensation elements, each reactive compensation element being coupled to one of the *k* sections and having a reactance that substantially cancels the series reactance of each section at the frequency; and

   (c) a current source coupled to the first and second magnetic current loops such that current flows in a first direction in the first magnetic current loop and in a second direction, opposite the first direction, in the second magnetic current loop thereby substantially canceling a dipole field at a distance spaced from the first and second magnetic current loops.

2. The magnetic current loop system of claim 1 wherein the series reactance of each of the *k* sections comprises an inductive reactance and each of the *k* reactive compensation elements comprises a capacitor.

3. The magnetic current loop system of claim 2 wherein each capacitor has a capacitance value C_k such that $\frac{1}{\omega C_k} = \omega L_k$, wherein ω is the

angular frequency of the current source and L_k is the series inductance of the k^{th} section of the magnetic current loops.

4. The magnetic current loop system of claim 1 wherein the k sections are substantially equal in length and the series reactances of the k sections are substantially equal.

5. The magnetic current loop system of claim 1 wherein at least some of the k sections are unequal in length and some of the series reactances of the k sections are not equal.

6. The magnetic current loop system of claim 1 wherein the current source is adapted to produce a current having a frequency of about 13.56 MHz.

7. The magnetic current loop system of claim 1 wherein the first magnetic current loop is located in a first plane and the second magnetic current loop is located in a second plane spaced from and parallel to the first plane.

8. The magnetic current loop system of claim 1 wherein each of the first and second magnetic current loops includes n turns, n being an integer.

9. The magnetic current loop system of claim 8 wherein n is equal to one.

10. The magnetic current loop system of claim 8 wherein *n* is greater than one.

11. The magnetic current loop system of claim 1 wherein the first and second magnetic current loops are coaxial with each other.

12. The magnetic current loop system of claim 11 wherein sections of the first magnetic current loop are substantially equal in length to adjacent sections of the second magnetic current loop.

13. The magnetic current loop system of claim 12 wherein the reactive compensation elements associated with sections of the first magnetic current loop are substantially equal in reactance to reactive compensation elements of the adjacent sections of the second magnetic current loop.

14. A reader for a magnetic-current-loop-based communication system, the reader comprising:

(a) first and second magnetic current loops, each being divided into *n* sections, *n* being an integer, each section having a series reactance;

(b) 2*n* reactive compensation elements, one element being associated with each of the 2*n* sections, such that the reactive

compensation elements substantially cancel the series reactance of each of the sections; and

(c) circuitry operatively associated with the first and second magnetic current loops for communicating with a device when the device is within a predetermined distance of the first and second magnetic current loops.

15. The reader of claim 14 wherein the first and second magnetic current loops are coaxial with each other.

16. The reader of claim 15 wherein the first and second magnetic current loops are connected to each other so that current flows in a first direction through the first magnetic current loop and in a second direction, opposite the first direction, through the second magnetic current loop.

17. The reader of claim 15 comprising:

(a) a third magnetic current loop positioned between and equidistant from the first and second magnetic current loops for coupling to a magnetic field from the device; and

(b) circuitry operatively associated with the third magnetic current loop for processing a signal modulated on the magnetic field from the device.

18. The reader of claim 17 comprising a microprocessor operatively associated with the circuitry for performing a predetermined function in response to the signal from the device.

19. The reader of claim 18 wherein the microprocessor is adapted to perform an authentication function in response to the signal from the device.

20. The reader of claim 18 wherein the microprocessor is adapted to store at least some of the information contained in the signal from the device in a memory device.

21. A magnetic current loop system comprising:

(a) a magnetic current loop being divided into *n* sections, n being an integer, each of the *n* sections having a series reactance at a frequency; and

(b) *n* reactive compensation elements respectively coupled to each of the *n* sections, each of the *n* reactive compensation elements having a reactance that substantially cancels the series reactance of the corresponding section at the frequency, thereby producing substantial current magnitude and phase uniformity along the magnetic current loop.

22. The system of claim 21 wherein the series reactance of each of the *n* sections comprises an inductive reactance and the reactance of each

of the respective compensation elements comprises a capacitive reactance.

23. The system of claim 21 wherein each of the *n* sections includes a series resistance, a series inductance, a shunt capacitance, and a shunt resistance, the shunt capacitance and the shunt resistance of each section having a first time constant, and wherein each of the reactive compensation elements has a reactance value such that the series resistance and an effective capacitive series reactance of each of the sections has a second time constant that is substantially equal to the first time constant.

24. A magnetic current loop system comprising:

(a) *n* magnetic current loops, *n* being an integer, each of the *n* magnetic current loops being divided into sections, each section having a series reactance; and

(b) reactive compensation elements respectively coupled to the sections, each of the reactive compensation elements having a reactance that substantially cancels the series reactance of the respective section.

25. The system of claim 24 wherein *n* is equal to one.

26. The system of claim 24 wherein *n* is greater than one.

27. The system of claim 24 wherein the *n* magnetic current loops comprise first, second, and third magnetic current loops being coaxial with each other, the third magnetic current loop being located between the first and second magnetic current loops.

28. The system of claim 27 comprising a first current source coupled to the first and second magnetic current loops adapted to produce a first current having a first magnitude and a first direction in the first and second magnetic current loops and a second current source coupled to the third magnetic current loop adapted to produce a second current having a second magnitude and a second direction in the third magnetic current loop, the second direction being opposite the first direction and the second magnitude being twice the first magnitude.

29. The system of claim 24 wherein the *n* magnetic current loops comprise first and second pairs of magnetic current loops being coaxial with each other.

30. The system of claim 29 wherein the first and second pairs of magnitude current loops each include an inner magnetic current loop and an outer magnetic current loop, and the inner magnetic current loops of each pair are adjacent to each other.

31. The system of claim 30 comprising a current source coupled to the outer magnetic current loop of each pair such that current flows in a

first direction in the outer magnetic current loop of each pair and to the inner magnetic current loop of each pair such that the current flows in a second direction opposite the first direction in the inner magnetic current loop of each pair.

32. The system of claim 26 comprising a current source coupled to each of the magnetic current loops such that current flows in the same direction in all of the magnetic current loops.

33. A method for reactively compensating magnetic current loops, the method comprising:

(a) dividing first and second magnetic current loops into *k* sections, *k* being an integer, each of the *k* sections having a series reactance at a frequency;

(b) adding reactive compensation to each of the *k* sections such that the reactive compensation substantially cancels the series reactance of each of the *k* sections;

(c) driving the magnetic current loops with a current source having a frequency such that current flows in a first direction in the first magnetic current loop and in a second direction in the second magnetic current loop; and

(d) placing the first and second magnetic current loops in close proximity to each other to substantially cancel dipole fields produced by the magnetic current loops.

34. The method of claim 33 wherein the series reactance of each of the *k* sections is a series inductive reactance and adding reactive compensation to each of the *k* sections includes adding a capacitor to each of the *k* sections.

35. The method of claim 33 wherein dividing the first and second magnetic current loops into *k* sections includes dividing the first and second magnetic current loops into *k* sections having substantially equal lengths such that the series reactances of the *k* sections are substantially equal.

36. The method of claim 33 wherein dividing the first and second magnetic current loops into *k* sections includes dividing the first and second magnetic current loops into *k* sections, at least some of which are unequal in length, such that the series reactances of at least some of the *k* sections are not equal.

37. The method of claim 33 wherein driving the magnetic current loops with the current source comprises driving the magnetic current loops with the current source having the frequency substantially centered about 13.56 MHz.

38. A method for reactively compensating a magnetic current loop, the method comprising:

(a) dividing the magnetic current loop into *k* sections, *k* being an integer, each of the *k* sections having a series reactance at a frequency; and

(b) adding reactive compensation to each of the *k* sections such that the reactive compensation substantially cancels the series reactance of each of the *k* sections at the frequency, thereby making the amplitude and phase of a current in the loop at the frequency substantially uniform throughout the loop and thereby providing more precise control over generation of a magnetic field at the frequency.

Abstract of the Disclosure

Methods and systems for compensating magnetic current loops provide current magnitude and phase uniformity within the magnetic current loops. A magnetic current loop is divided into *k* sections. Each of the *k* sections has a series reactance. Series reactive compensation is added to each of the *k* sections such that the reactive compensation substantially cancels the series reactance of each section. Adding reactive compensation to the loop that cancels the series reactance of each section of the loop provides current magnitude and phase uniformity along the loop at any given instant in time. As a result, the magnitude and phase of the magnetic field at a point in space can be controlled with precision to achieve a desired result, such as precise field cancellation or precise field generation.

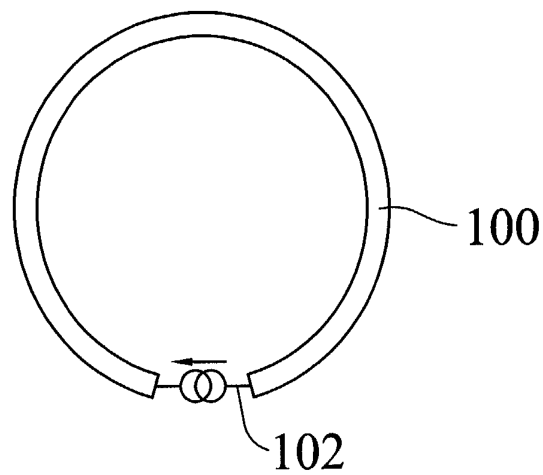


FIG. 1

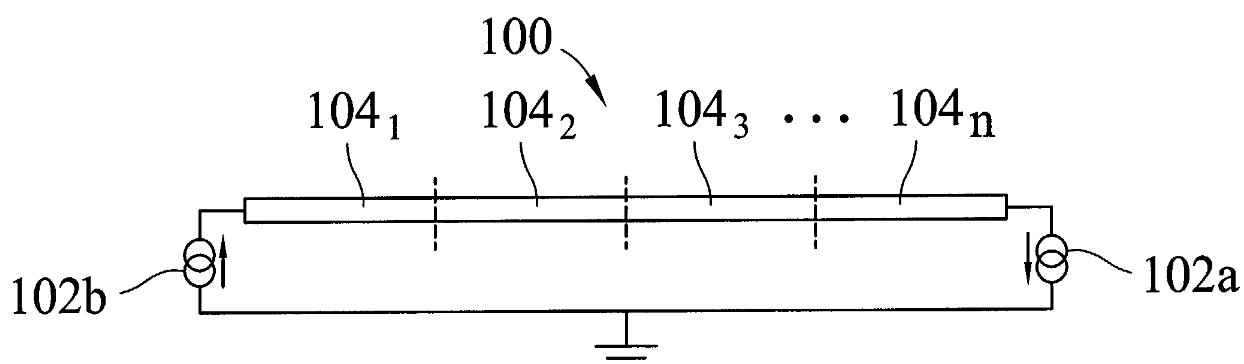


FIG. 2

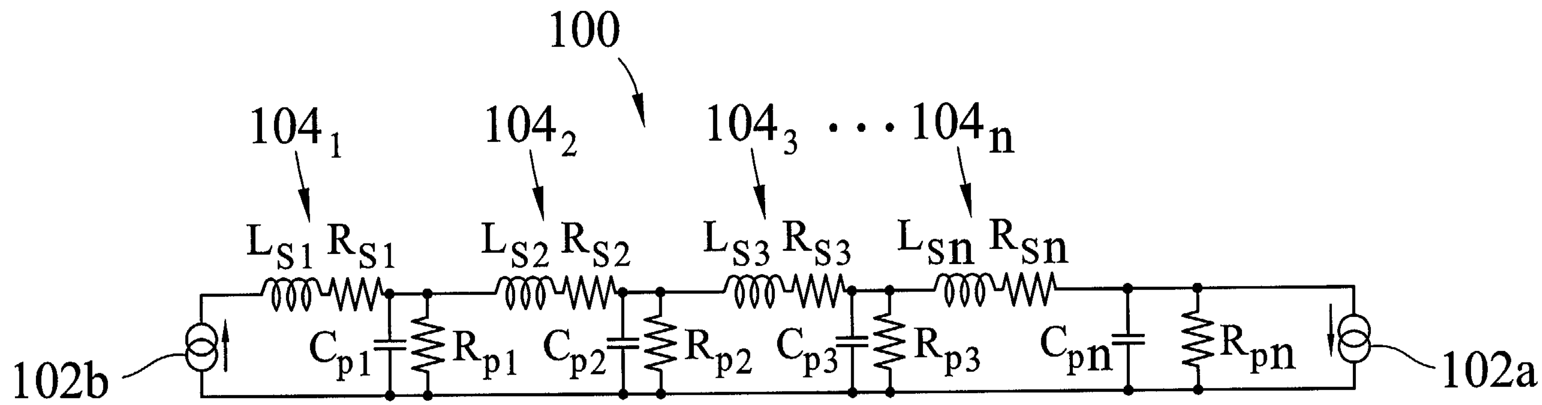

100
104 1
104 2
104 3 · · · 104 n
L S1 R S1
L S2 R S2
L S3 R S3
L Sn R Sn
C p1
R p1
C p2
R p2
C p3
R p3
C pn
R pn
102b
102a

FIG. 3

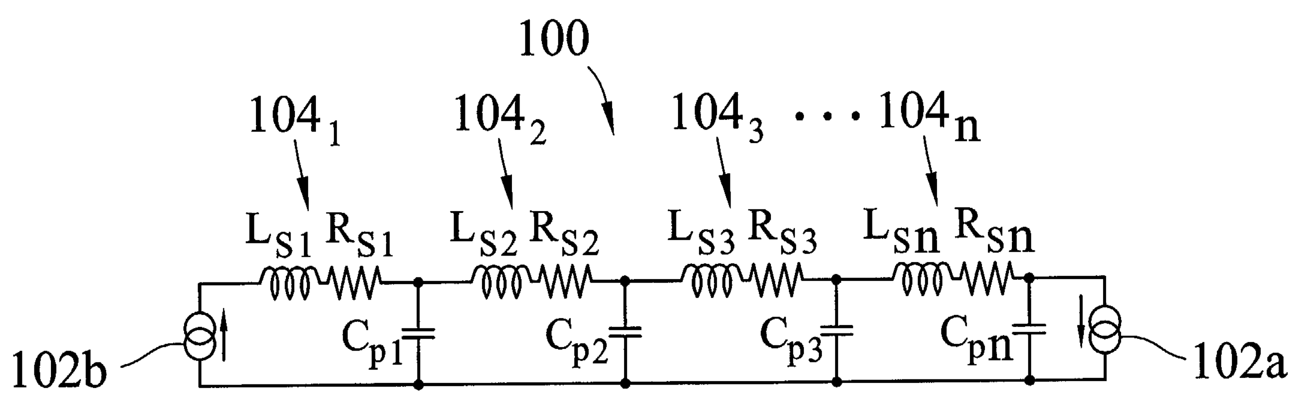

100
104 1
104 2
104 3 · · · 104 n
L S1 R S1
L S2 R S2
L S3 R S3
L Sn R Sn
C p1
C p2
C p3
C pn
102b
102a

FIG. 4

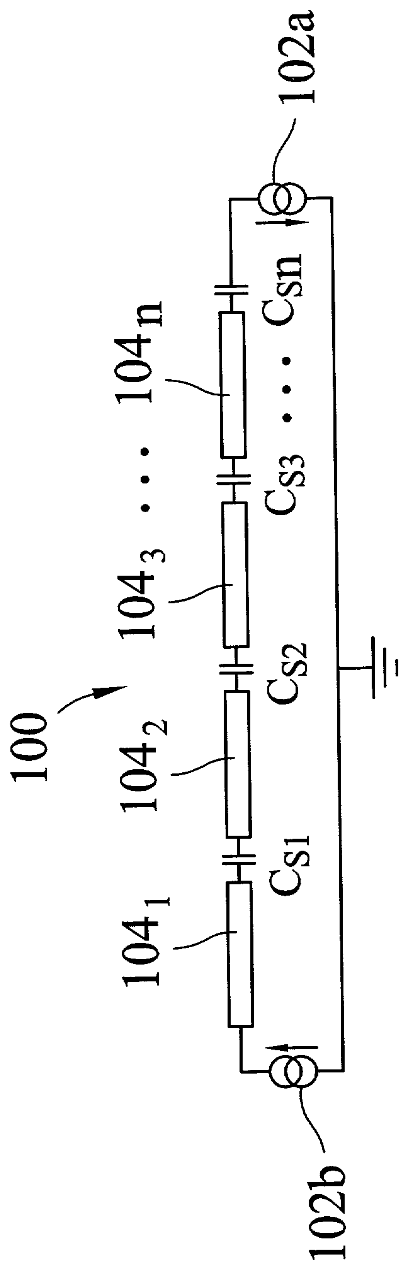

100
104₁
104₂
104₃
104ₙ
Cs1
Cs2
Cs3
Csn
102a
102b

FIG. 5

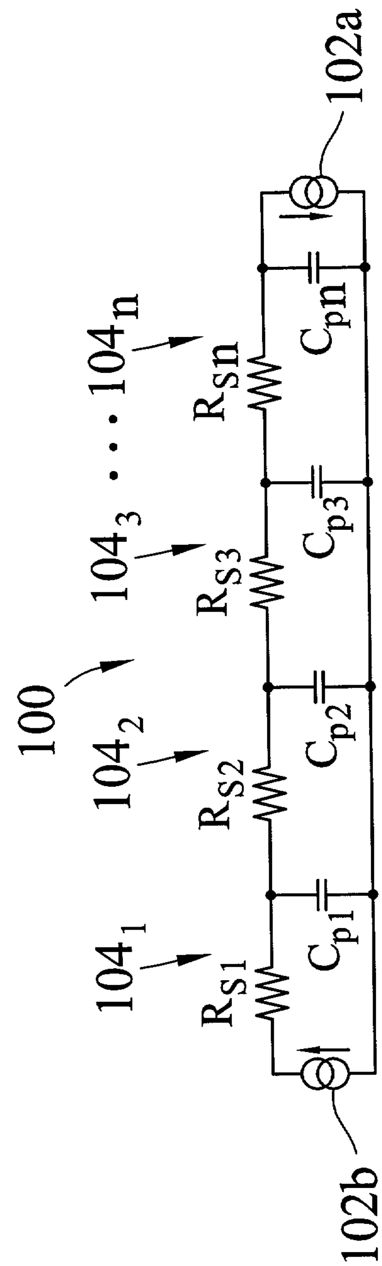

100
104₁
104₂
104₃
104ₙ
Rs1
Rs2
Rs3
Rsn
Cp1
Cp2
Cp3
Cpn
102a
102b

FIG. 6

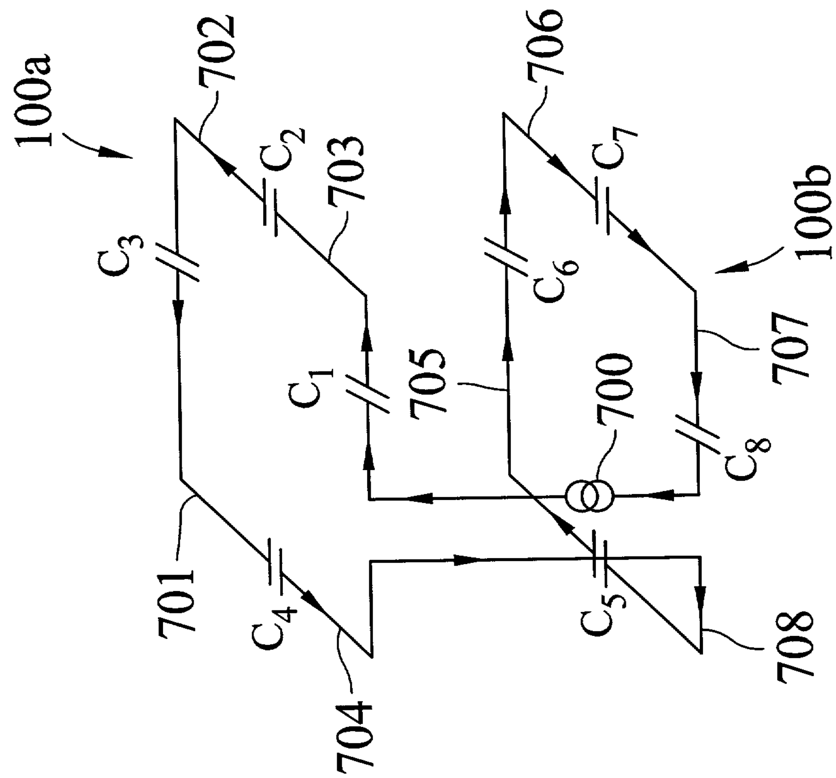

100a
702
C_2
703
C_3
C_1
705
706
C_7
100b
C_6
700
707
C_8
701
C_4
C_5
708
704

FIG. 7(a)

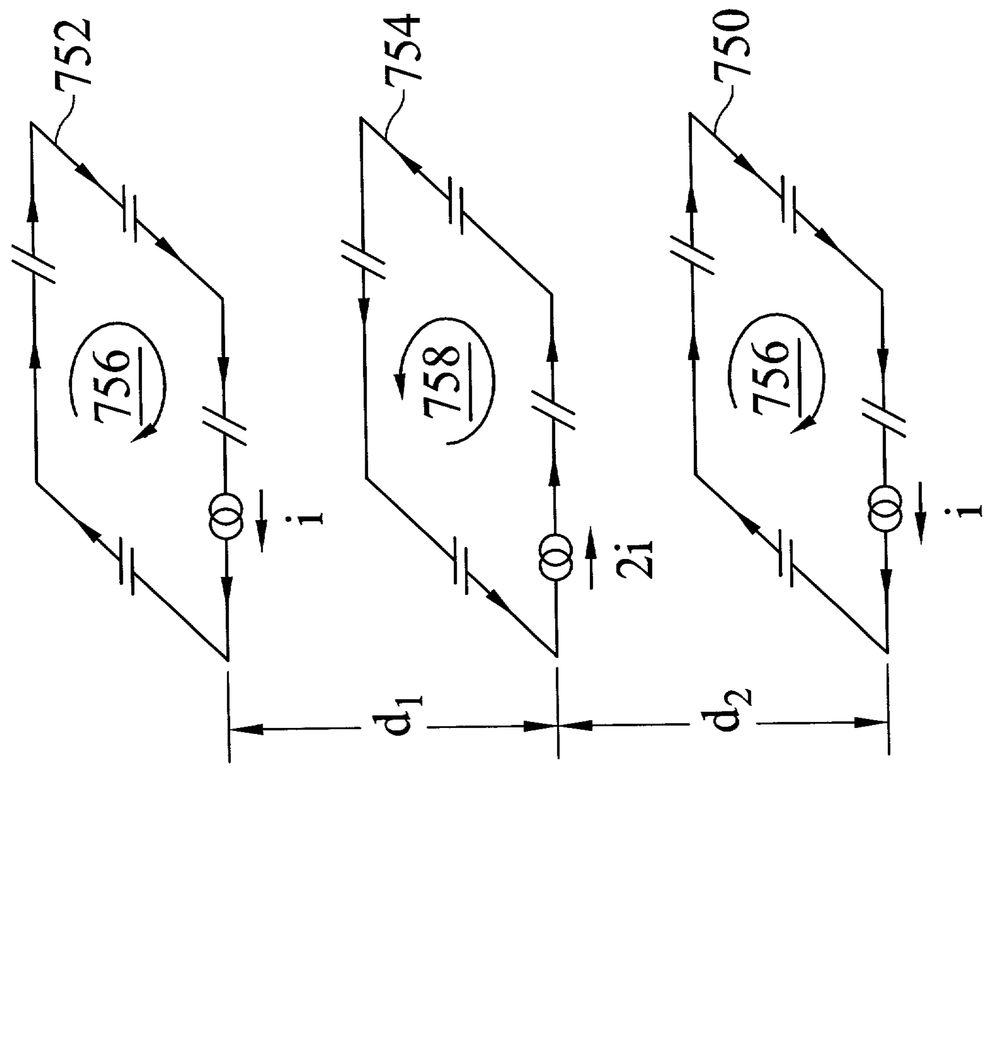
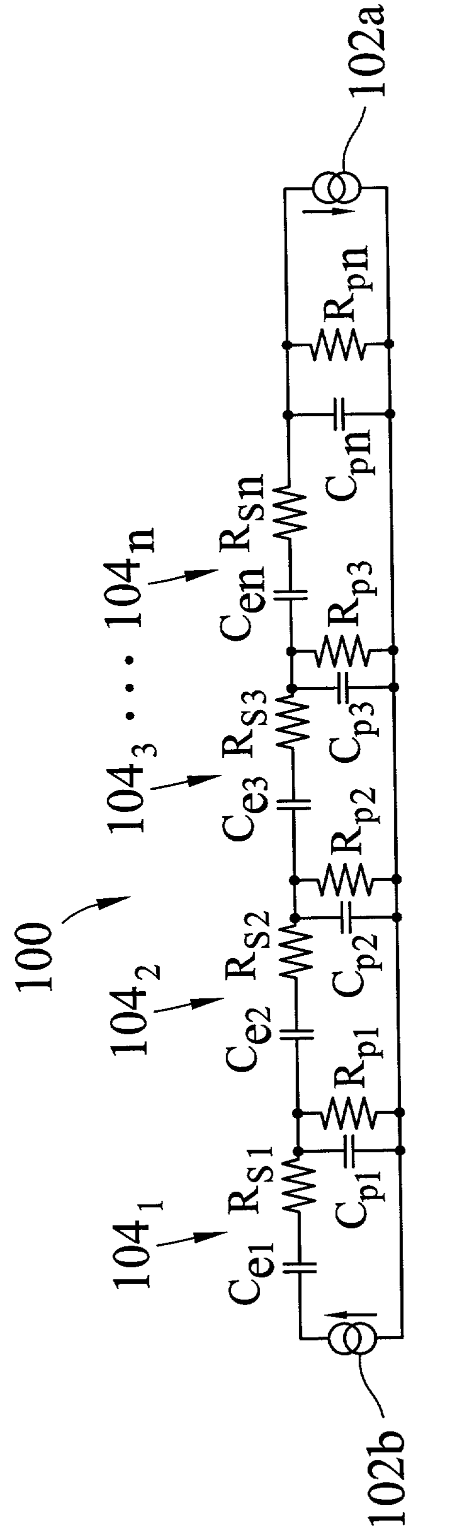


FIG. 7(b)



100
102a
102b
104_1
104_2
104_3 · · · 104_n
C_{e1}
R_{S1}
C_{p1}
R_{p1}
C_{e2}
R_{S2}
C_{p2}
R_{p2}
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C_{p3}
R_{p3}
C_{en}
R_{Sn}
C_{pn}
R_{pn}

FIG. 8

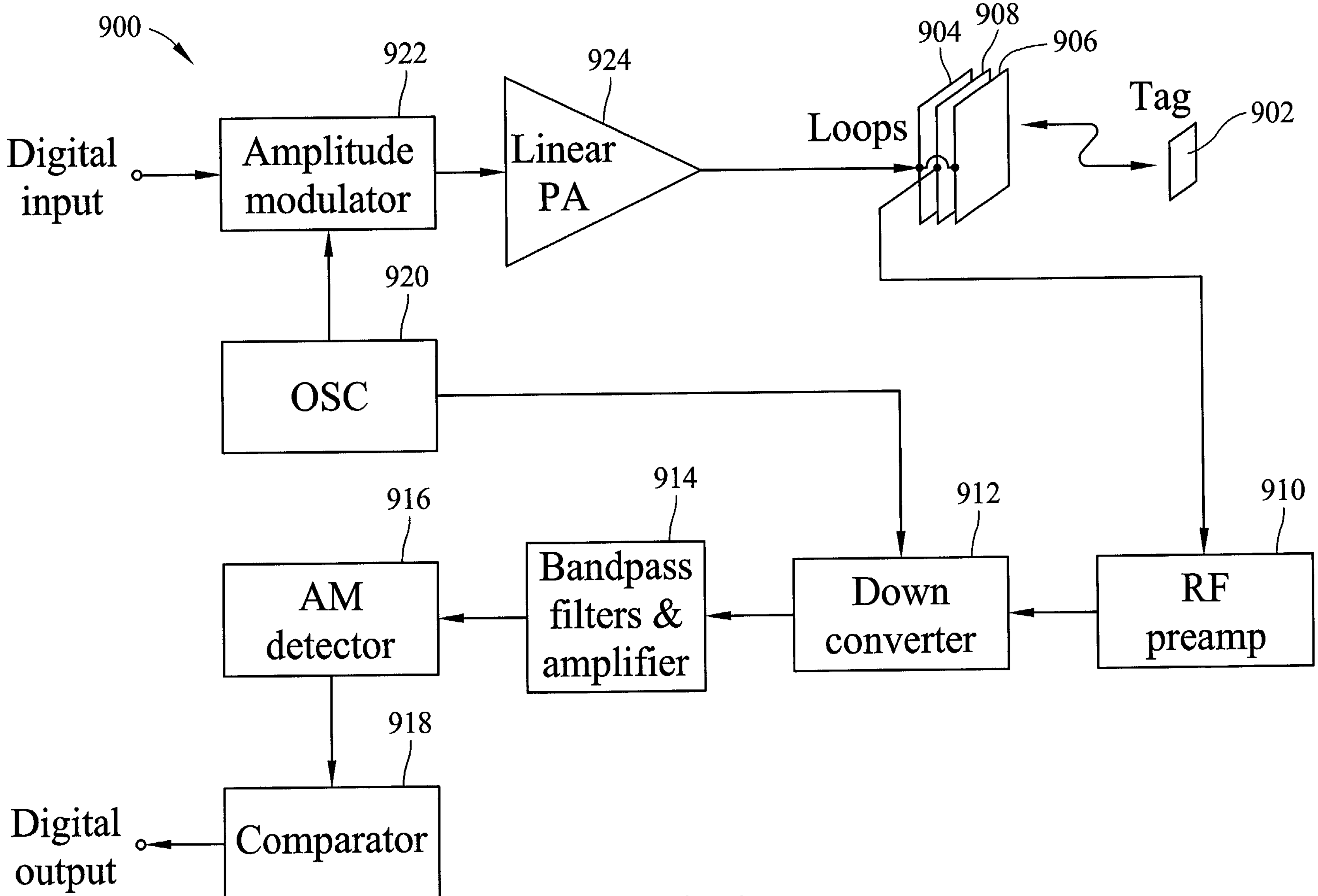
900
Digital input
Amplitude modulator
922
Linear PA
924
Loops
904
908
906
Tag
902
OSC
920
AM detector
916
Bandpass filters & amplifier
914
Down converter
912
RF preamp
910
Digital output
Comparator
918

FIG. 9

Please type a plus sign (+) inside this box → [+]

PTO/SB/01 (12-97)
Approved for use through 9/30/00. OMB 0651-0032
Patent and Trademark Office, U S. DEPARTMENT OF COMMERCE

DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)

[X] Declaration Submitted with Initial Filing **OR** [ ] Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16 (e)) required)

Attorney Docket Number	421/31
First Named Inventor	Vicci, Leandra
COMPLETE IF KNOWN	
Application Number	
Filing Date	
Group Art Unit	
Examiner Name	

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

METHODS AND SYSTEMS FOR REACTIVELY COMPENSATING MAGNETIC CURRENT LOOPS

(Title of the Invention)

the specification of which

[X] is attached hereto

OR

[ ] was filed on (MM/DD/YYYY) [ ] as United States Application Number or PCT International Application Number [ ] and was amended on (MM/DD/YYYY) [ ] (if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1 56

I hereby claim foreign priority benefits under 35 U S C 119(a)-(d) or 356(b) of any foreign application(s) for patent or inventor's certificate, or 356(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]

[ ] Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

I hereby claim the benefit under 35 U.S C 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)	
60/169,726	12/08/1999	[ ] Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

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DECLARATION — Utility or Design Patent Application

I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application or PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number (if applicable)

☐ Additional U.S. or PCT international application numbers are listed on a supplemental priority data sheet PTO/SB/02C attached hereto.

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OR
☐ Registered practitioner(s) name/registration number listed below

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25297

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Name	Registration Number	Name	Registration Number

☐ Additional registered practitioner(s) named on supplemental Registered Practitioner Information sheet PTO/SB/02C attached hereto.

Direct all correspondence to: ☐ Customer Number or Bar Code Label [ ] OR [X] Correspondence address below

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon

Name of Sole or First Inventor: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname
Leandra	Vicci

Inventor's Signature						Date	
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Post Office Address	2940 Mt. Vernon HMR						
Post Office Address							
City	Siler City	State	NC	ZIP	27344	Country	US

[X] Additional inventors are being named on the 1 supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto

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PTO/SB/02A (3-97)
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DECLARATION

ADDITIONAL INVENTOR(S)
Supplemental Sheet
Page 1 of 1

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname
Wayne D.	Dettloff

Inventor's Signature						**Date**	
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Post Office Address	405 Livingstone Drive						
Post Office Address							
City	Cary	**State**	NC	**ZIP**	27513	**Country**	US

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname

Inventor's Signature						**Date**	
Residence: City		**State**		**Country**		**Citizenship**	
Post Office Address							
Post Office Address							
City		**State**		**ZIP**		**Country**	

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname

Inventor's Signature						**Date**	
Residence: City		**State**		**Country**		**Citizenship**	
Post Office Address							
Post Office Address							
City		**State**		**ZIP**		**Country**	